ART. LIX.—*Notes on the sub-marine channel of the Hudson River and other evidences of Post-glacial Subsidence of the Middle Atlantic Coast Region;* by A. LINDENKOHL. With Plate XVIII.

THE American Journal of Science of 1885† contained an article by the writer entitled "Geology of the Sea Bottom in the Approaches to New York Bay," in which a description was given of a remarkable depression in the sea bottom off Sandy Hook and an attempt was also made to account for the origin of this depression and to trace its connection with the geology of the adjacent coast region.

Professor Dana, who was the first to recognize the true shape of this depression and to direct attention to its existence by a map and reference in his "Manual of Geology," published in 1868, takes up the subject again in a recent number of this Journal,‡ treating of Long Island in the Quaternary with observations on the sub-marine Hudson River channel, and carefully

* M. G. Rousseau, in the new Encyclopédie Chimique, seems to entirely abandon the old view of extreme division and considers these forms to be allotropic and comparable with the allotropic forms of phosphorus, etc. Vol. iii, page 56.

† Vol xxix, pp. 475 et seq., also republished as Appendix No. 13, U. S. Coast and Geodetic Survey, Report of 1884.

‡ Vol. xl, pp. 425–437.

reviews the well-ascertained facts connected with this depression but on several points reaches quite different conclusions.

It is the object of the following pages to review the subject, and at the same time to introduce much information bearing upon it, which has accumulated since 1885, but has not appeared in print.

Description of the Sub-marine Hudson River Channel.—The sub-marine depression, to which reference is made in the preceding paragraphs, has the characteristics of a river channel unmistakably impressed upon it and it is recognized as the submarine continuation of the Hudson River channel. It is first noticed at a depth of twenty fathoms, about twelve statute miles southeast from Sandy Hook. Its course is nearly south until abreast of and eleven miles from Long Branch, where it has attained a depth of thirty fathoms in fifteen fathoms of water. Thence it begins to turn to the southeast and attains its greatest depth of forty-five fathoms when fifty-three miles from Sandy Hook, the banks rising on both sides of the channel to a height of fifteen fathoms within two or three miles. From here its depth begins to fall off until, at a distance of ninety-one miles from the Hook, the channel almost disappears with a depth of but forty-one fathoms in a surrounding bottom of thirty-nine fathoms depth. But, at a distance of ninety-seven miles, the channel begins to assume the character of a gorge or cañon, which character it maintains for a length of twenty-three miles, when it vanishes on the edge of the great continental plateau at a depth of about 200 fathoms. The average width of the river channel is about $1\frac{1}{4}$ miles, that of the gorge three miles with a greatest depth of 474 fathoms in about seventy fathoms of water.

The bottom of the river channel and cañon as well as their slopes consist of a bluish slate-colored mud or clay with a fine sandy grit. This mud bottom extends for a considerable distance on both sides, north and south of the cañon along the brink of the continental plateau.

In trying to account for the existence of the upper part, or river portion, of the channel, it was assumed to be the result of fluvial erosion and to imply a subsidence of about 210 feet at a comparatively recent geological time, subsequent to the glacial period. The existence of the gorge was believed to imply a much greater subsidence than that of the upper channel, a subsidence not far from 1200 feet (200 fathoms). No attempt was made to fix its geological date beyond the statement that its fiord-like shape favors the supposition that it existed as an elevated channel during a part at least of the glacial era, but that it must have sunken below the level of the ocean at the time when its feeder was yet an actual river channel.

The presence of clay on the bottom of the channels and on the slopes, and its absence elsewhere, was assumed to furnish proof for the assumption that this clay was not a mere superficial covering, but that it is formed *in situ* and gives indications of strata in correlation with the Tertiary exposed towards the northeast at Gay Head, as well as with that of New Jersey, bearing west.

The first one of these propositions, the one which accounts for the sunken river channel, is the most important and perhaps the most vulnerable one, and requires proof of the following corollaries:

1st. The shape and dimensions of the channel must accord with those which should be assigned to a hypothetical river of the size of the Hudson.

2d. Tidal and other currents now in existence cannot have produced the channel.

3d. A similar subsidence which must not necessarily be of the same amount, must be proved for the nearest rivers to the south, for the Delaware, Susquehanna (or Chesapeake) and Potomac. (The rivers to the north may be left untouched since Professor Dana has investigated the subject and recorded the results in his paper on Long Island Sound in the Quaternary, etc., mentioned above.)

4th. It must be shown that diluvial deposits do not lie conformably on the surface of these channels but are eroded by them, and all deposits found in the channels must be of alluvial character.

1. *Size and shape of the Sub-marine Hudson River Channel.*—The breadth of the channel is about one and a quarter miles, about the same as that of the river above the Narrows. From New York City to the Dunderberg the channel is about three-quarters of a mile wide. These dimensions tally well with the conditions expected from an ordinary tidal stream, i. e. increased capacity with nearer approach to sea. The main slope of the banks is 1°. This is less than we expect of living rivers, but we should take into consideration that, apart from currents, the corrasive action of sea water is constantly engaged upon the work of destruction. It is rather a matter of surprise to those who are familiar with the little power of resistance of clay banks in sub-aerial exposure when unprotected by gravel ledges or turf, that such banks should be preserved at all under the sea. No special reason can be assigned for the peculiarity that the river should first flow fifteen miles to the south before turning east unless we assume that it follows the fashion set by its neighboring rivers, the

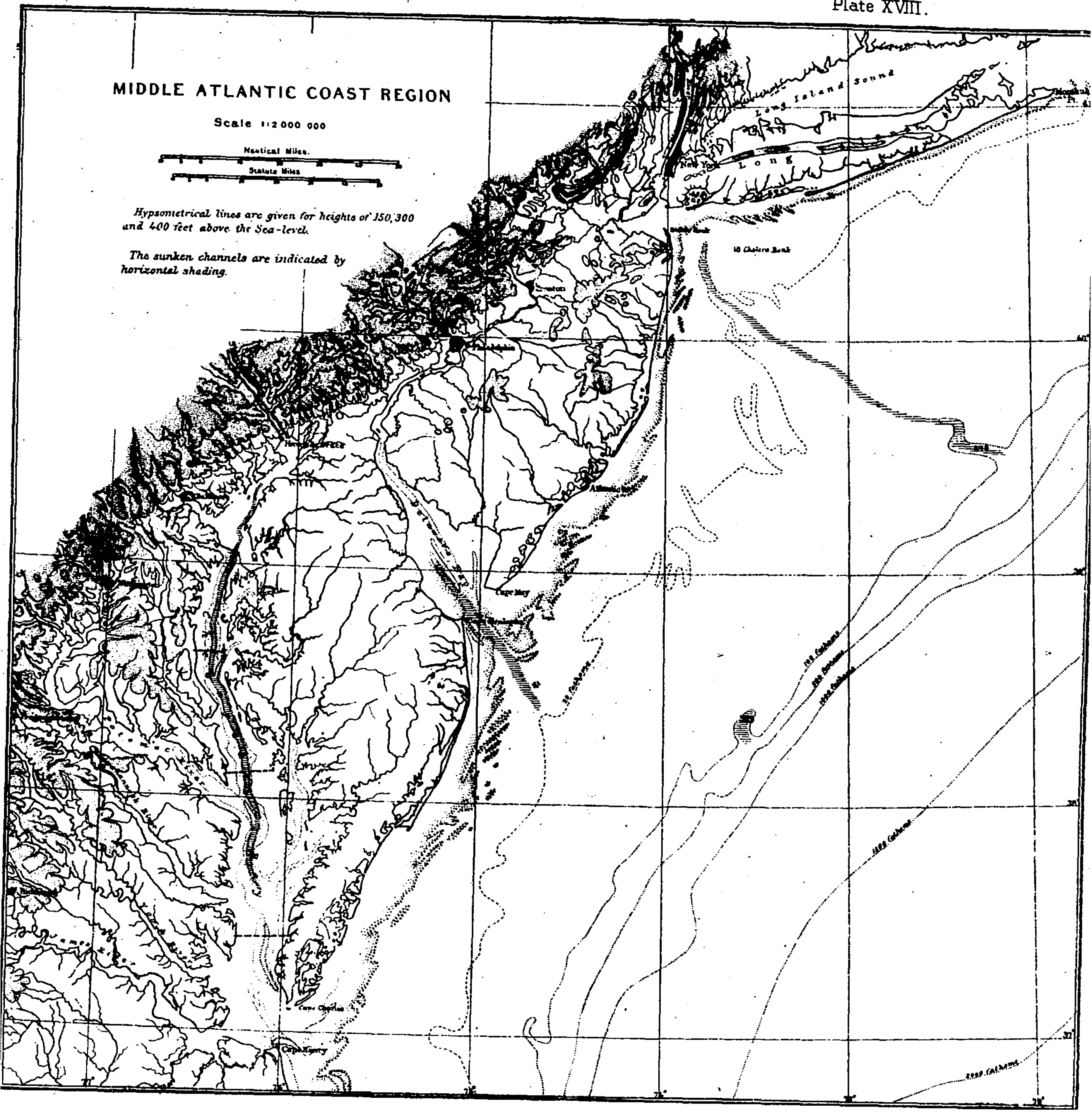
Delaware, Susquehanna, and Potomac, which all follow a southern and anticlinal course before they take up the straight road to sea. This uniformity in behavior of these four rivers points to a common cause, and a slight tilting of the Atlantic plain in a north and south direction suggests itself as the readiest way to account for the southern deflection of the rivers.

Effects of existing currents on the sub-marine channel.—The following table, giving the mean maximum strength of both sets of tidal currents in nautical miles, has been compiled from the latest observations for the purpose of testing the ability of those currents to create channels outside of the Sandy Hook bars.

Table of Tidal Currents in the lower New York Bay.

	Mean Maximum Ebb.		Mean Maximum Flood.	
	Surface.	Bottom.	Surface.	Bottom.
Narrows	1·9	0·9	1·3	1·0
Fourteen Foot Channel	1·9	0·9	1·6	1·0
East Channel	2·2	0·9	1·6	0·8
Swash Channel	2·1	0·9	1·8	1·2
Main Ship Channel	2·3	0·8	1·8	1·2
Outer East Channel	2·1	1·2	1·6	0·9
Gedney's Channel	2·3	0 9	1·8	1·0
South Channel	2·2	0·2	1·4	0·7

It will be seen from this table that the ebb current is the strongest surface current and maintains its velocity (1·9 to 2·3 knots) until the outer bars have been passed. But its strength at the bottom of the channels is less than half that of the surface currents, and less than that of the flood current. The flood current is essentially a deep current and retains at the bottom, in spite of friction, nearly two-thirds of its surface velocity; it is the flood current's speciality to attend to the scouring business. But we cannot realize that a current which has but 1·2 nautical miles velocity at the places where it must be supposed to exert its greatest strength, can have the power to scoop out a channel forty-five feet deep and only a mile wide at a distance of fifty miles from the coast. At the same time the opinion is well-founded that the submarine channel is the principal passage way for the tide to and from New York Bay, and that this almost ceaseless flow tends to keep the channel clear from encroachments, especially by that formidable bank, the Cholera Bank on the New York side of the channel. Often the tides may be reinforced by high seas produced by continuous easterly winds off New York; and although such high tides are known to be very destructive along the whole coast from Atlantic City to Fire Island, we have no reason to believe their effect to extend to greater depths than fifteen fathoms or to the depth of our channel.

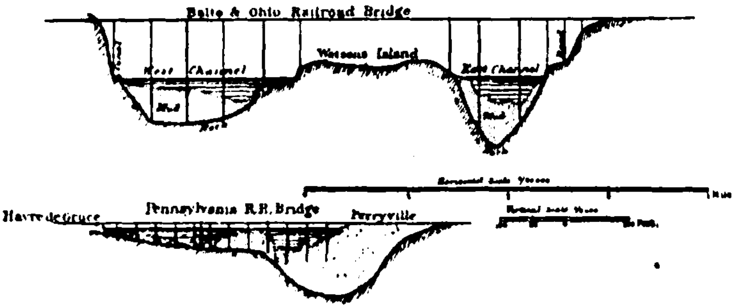

MIDDLE ATLANTIC COAST REGION
Scale 1:2 000 000
Nautical Miles.
Statute Miles
Hypsometrical lines are given for heights of 150, 300 and 400 feet above the Sea-level.
The sunken channels are indicated by horizontal shading.
Long Island Sound
Long
New York
Philadelphia
Cape May
Cape Charles
Cape Henry
James R.

Sunken River Channel in Chesapeake Bay.—As stated above, if the theory of a recent subsidence of the Hudson River is to be successfully maintained, a similar subsidence *must* be proved for the Delaware and for Chesapeake Bay. It must be confessed that for many years we have been searching for sunken channels for those bays without finding them; we were looking for them in a wrong direction, outside of the bays, instead of inside. We supposed Cape Henlopen and Cape Henry occupied relative positions to those channels analogous to that of Sandy Hook to the sunken Hudson River channel; we took the Coast-line as our line of departure instead of taking the *Fall-line.* This line which is easily identified by the site of New York, Trenton, Philadelphia, Havre de Grace, Baltimore, Washington, etc., separates two widely different geological regions, the region of crystalline and Triassic rocks to the north and west from the stratified clays and gravels to the south and east, and it must be assumed that any seismic disturbance would affect these two regions unequally and the coastal plain to a greater extent than the Piedmont region.

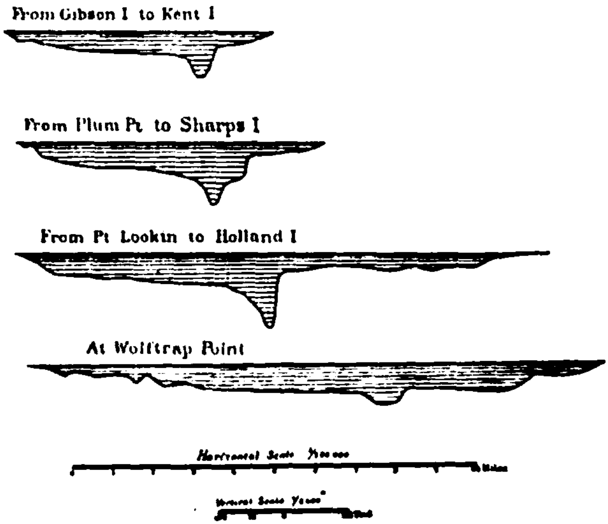
Now, the *sinking* of the land to the extent of 100 feet, let us say fifty feet, would hardly affect the physiography of those parts of the country above the hypsometrical line of fifty feet, but all land below this level would be appropriated by the waters and reached by the tides; rivers with low shores would be converted into bays or estuaries, those situated in rising ground would have the lower parts of their valleys flooded. It now remains for us to examine Delaware and Chesapeake Bays for traces of deeper and narrower channels than those which can be accounted for by existing conditions.

Passing Delaware Bay, for reasons which will be explained farther on, and turning to Chesapeake Bay, we readily find, upon examining the soundings, a narrow and deep inner channel which can be traced nearly through the entire length of the bay, from the mouth of Bush River to that of the Rappahannock, a distance of 120 miles. In an average width of the bay of ten miles, this channel commences with one mile's breadth in its upper part, increasing to two miles near its southern limit. The descent of the bottom of the bay is very gradual from the shore until the depth of eight fathoms is passed, when the bottom abruptly plunges to the depth of about twenty fathoms (from fifteen to twenty-six fathoms). The bathymetrical line of forty-eight feet may then be taken as the limit of this inner deep channel. We subjoin four cross-sections of the bay, taken about thirty-five miles apart. It will be seen that the areas of these sections are gradually increasing, going down the bay and that the last one, that off Wolftrap Point below the Rappahannock, is the largest, although the

Cross Sections of the Susquehanna River



Cross Sections of Chesapeake Bay



deep cut in the bottom is missing. It does not matter what particular curve we accept as a type of cross-sections of tidal streams, whether an ellipse or parabola, the cross-section at Wolftrap comes nearer to it than any of the preceding ones and no combination of circumstances, no shifting or turning of channel can satisfactorily explain, as a purely tidal phenomenon, the existence of the deep incisions at the bottom of the cross-sections. We are forced to conclude that these incisions are due to pre-existing conditions, that they show the former channel of a river at a time when the whole region lay about forty-eight feet higher than at present, when Chesapeake Bay did not exist, but when the Susquehanna was at least 150 miles longer than at present (rather more than the submerged Hudson) and gathered upon its way to the sea the waters of the Patuxent, Potomac and Rappahannock. The reason that we cannot trace the channel farther up the bay than Bush River and to the mouth of the Susquehanna is, no doubt, owing to the fact that the Susquehanna has filled up the upper part of its old channel, for which it has no further use, with its sediment; and the borings to a depth of 140 feet at Fishing Battery, below Havre de Grace, through alluvium, which Mr. McGee reports,* quite favor such a supposition. As stated above, the channel disappears below the mouth of the Rappahannock with a depth of about fifty feet. I am not prepared now to answer the question, whether the bar and actual end of the old river is here or whether there is but a temporary interruption of the channel by subsequent deposits from rivers emptying into the bay. The answer is not material to the present inquiry. The river channel appears to have hugged its eastern shore, which in several places appears to have risen into bluffs, from 15 to 25 feet high, while the western shore was low and marshy. The soundings in the bay are not the only indications of a depression; they can be found everywhere along the shores of the bay, even by a mere inspection of the charts. It is entirely beyond the ability of the present sluggish streams to have eroded their channels to the great width which is so characteristic of the lower part of all streams entering the Chesapeake. The absence of deltas and bars at the mouths of the rivers, the almost total absence of drainage-area for a long strip of the western shore of the bay above the Rappahannock, all are suggestive of subsidence, in fact have been commented upon in this direction by Mr. McGee in his exhaustive study of the Geology of Chesapeake Bay.† On more than one occasion he speaks of the drowned rivers of the bay.

There is another way in which we may arrive at an estimate of the probable amount of subsidence. The profile given (p. 494) of the Susquehanna River at the crossing of the Baltimore and

* Seventh Annual Report U. S. Geological Survey, p. 560.

† Seventh Annual Report, U. S. Geological Survey, pp. 537–646.

Ohio Railroad bridge above Havre de Grace, kindly furnished by Mr. Chas. F. Mayer, the President of the road, shows a considerable layer of mud intervening between the bottom of the river and the rocky granite floor. This layer has a thickness of fifty-nine feet in the west, and over seventy feet in the east channel. The river would most certainly not have cut a channel into one of the hardest of rocks if there had not existed, at some time, a physical necessity for it, and the amount of filling or "packing" of mud enables us to estimate the depth of the river at that time. Assuming the discharge to be stationary, we find that, supposing the mud to be removed, the river could be lowered forty-three feet and yet find sufficient space for the passage of its waters. The next profile (p. 494) is from the crossing of the Pennsylvania Railroad at Havre de Grace, about one mile to the southward of the B. & O. R. R. bridge. This profile was obtained from Mr. G. B. Roberts, President of the Penna. R. R. It shows the greatest depth of mud, 113 feet under the wharf at Perryville. It would appear then that the channel of the river ran very closely to its eastern shore which was then several hundred feet farther inland. The rock is stated by Mr. McGee to dip under the level of the river about one-quarter of a mile from the railroad bridge. A similar calculation for the level of the river with the rocky floor for its bed, instead of the muddy bottom, gives fifty feet below the present surface. These two estimates taken in connection with the result of borings at Fishing Battery mentioned above, would appear to prove that at the time when the level of the Chesapeake was forty-eight or fifty feet lower with respect to the land than at present, Perryville and not Port Deposit, was at the head of tide and that strong currents swept down the Susquehanna past and on both sides of Watson Island, plowing into the clays of the coastal plain to a depth of ninety feet or more.

The Potomac being a tributary of Chesapeake Bay, we should naturally expect indications of a sinking of the land at the head of tide, similar to those of the Susquehanna. An examination of several profiles of the river at the Free Bridge in Georgetown (the former Aqueduct Bridge, built about 1840) shows the excavation of the channel to be of quite different shape from that of the Susquehanna; it is flat at the bottom and only reaches to the depth of thirty-five feet from the surface. There was considerable "packing" by mud before the bridge was built, about thirteen feet thickness on an average. The cross-section of the river was considerably curtailed by the construction of the bridge. The river has tried to regain its former status and nearly succeeded in this effort, by removing the greater part of the mud at its bottom. Supposing all the mud and artificial obstructions to be removed, the river could stand a lowering of its level of but eleven feet. Judging from surface exposures, the rocks at the bottom of the river are frangible or disintegrated gneiss, which is certainly less obdurate than the granite of the Susquehanna gorge, hence we have to conclude that the dislocation here is scarcely one-fourth of that of the Chesapeake Valley. At the site of the proposed Memorial Bridge, 1000 feet east from Easby's Wharf, rocky bottom is found at a depth of forty-four feet below the surface of the river; the stratum of mud here is about fifteen feet thick. At the Long Bridge, rock bottom has not been reached by boring or pile driving, and hard bottom in the Washington channel is seventy-one feet below the surface under a layer of sandy mud of sixty-nine feet thickness. The Georgetown channel has no mud at its bottom but runs over a hard bed of gravel and clay. A subsidence along the valley of the Potomac below Washington, inferior to that of Chesapeake Bay, is attested by the bay-like expansion of all the affluents at their mouths.

Subsidence in Delaware Bay.—I have not had the necessary time nor data at hand to make a similar inquiry about probable subsidence in Delaware Bay. In fact, we know Delaware River and Bay to have much stronger currents and to carry a greater amount of coarser sediment than Chesapeake Bay, and are prepared to find the traces of a former higher level less distinctly preserved. Nevertheless, we can trace a deep channel from the ocean into the middle of the bay where it is apparently choked off by alluvial deposits which fill up the entire upper part of the bay, leaving just enough room for the river channel. This "blind channel" has a depth of from twenty-two to thirteen fathoms, and is separated from the main river channel by shallow banks. The ebb-channel in actual use by the river has but a depth of three and one-quarter fathoms in its shoalest reaches. A comparison of our recent surveys with those made about fifty years ago proves that the high-water line, on the New Jersey side at least, has receded about one-eighth of a mile in the lower bay; but it would be rash to make subsidence responsible for this result. A comparison of the hydrographic surveys made about the same respective dates shows that there has been a great deal of shoaling going on in the interval, and it is not impossible that this shoaling has produced a disarrangement of the tidal elements, a retardment accompanied by an increase in amplitude which would show its effects on the high-water line.

Time of subsidence.—The evidence of a subsidence of the coast of New Jersey during the past century and yet in progress, collected by the late Professor Cook, must be considered as the main support of the theory which accounts for the existence of the submarine channel of the Hudson by submergence. In order to approximate the time of commencement of subsidence we have to take the evidence afforded by the latest Quaternary deposits. According to Mr. McGee* the clay terraces on which the city of Washington is built and which are supposed to be cotemporary with the first glacial invasion, indicate a submergence of about 150 feet during the period of their deposition. Hence it appears that the Lower Potomac and Chesapeake Bay with their depressed channels are of more recent origin. The borings at Fishing Battery cited above, which went to a depth of 140 feet and brought nothing to light older than alluvium, teach us that the deep channel of the Chesapeake must be of more recent date than any of the Tertiary and Quaternary deposits about the head of the bay.

The submarine border of the coast.—Returning to the subject of submarine channels, it has to be stated that diligent search has thus far failed to discover indications of such for either Chesapeake Bay or Delaware Bay, with the exception of a deep *cul-de-sac* of 396 fathoms inside of the bathymetric line of 100 fathoms, occupying nearly the same relative position to Delaware Bay as the cañon described above does to the Hudson.

In studying the geological changes in the sea bottom off the Middle Atlantic States, a remarkable fact should not be lost sight of. The sea bottom intervening between the submarine Hudson river channel and the coast of Long Island is characterized by its great regularity and smoothness, which can best be explained by assuming a gradual subsidence or an adjustment by superficial deposits. The bottom between the channel and the New Jersey coast, on the contrary, is distinguished for its ruggedness; great irregularities in the soundings give indications of shallow ridges and of cross channels, which go to prove that there was a periodical retrogression of the coast line, and that the sea keeps the conquered territory in very much the same condition in which it was found.

Greensand at the sea bottom.—The specimens of bottom collected during the recent survey of the approaches to New York, of which there are several hundreds at hand, show considerable quantities of black grains, described black specks on the charts, mixed up with the sand and mud of the entire region from Cape May to beyond Montauk Point; it is only in the mud of the gorge and of the deeper part of the continental slope that they are either scarce or missing. They are of spherical shape, of jet black luster, of brown color when fractured, and vary in size, with the fineness of the sand or mud, from the

* This Journal, vol. xxxv, May, 1888.

size of a pin-head to microscopical dimensions. They were evidently not composed of hornblende, and I hesitated to pronounce them greensand, which material Mr. Pourtalès, in 1869, reported to exist in the sands off Long Branch and Rockaway Beach.* Mr. McGee was kind enough to have an examination made in the laboratory of the U. S. Geological Survey and informs me "that the black grains are, as Count Pourtalès supposed, glauconite. The mineral seems to have undergone a curious alteration and the grains were polished through attrition and partly through chemic and mechanical alteration akin to that of nodulation, but the density, optical properties, hardness, etc., of the broken grains are identical with the like properties of New Jersey greensand from the Cretaceous and Eocene." It was an open question with Mr. Pourtalès whether these grains were washed out to sea from the marl beds of New Jersey or belonged to beds cropping out at the sea bottom. In view of the great extent of ground over which these grains are spread, and the great distance from the New Jersey coast, close to Montauk Point for instance, the first supposition can no longer be maintained; they must be treated either as belonging to marl beds laid bare by the sea or as the remnants of such which have been destroyed by the sea.† Whether these beds were Cretaceous or Eocene strata is a question which probably can only be decided upon paleontological grounds, but the preponderant strength of the Cretaceous on the mainland certainly speaks in favor of the latter having supplied the greatest amount of greensand grains to the ocean's bottom.

March 26, 1891.